



US005978662A

# United States Patent [19]

Swales

[11] Patent Number: 5,978,662  
[45] Date of Patent: Nov. 2, 1999

[54] CIRCUIT ARRANGEMENT COMPRISING A  
CARTESIAN AMPLIFIER

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[21] Appl. No.: 08/882,872

[22] Filed: Jun. 26, 1997

[30] Foreign Application Priority Data

Jun. 28, 1996 [EP] European Pat. Off. .... 96110467

[51] Int. Cl. 6 H01Q 11/12

[52] U.S. Cl. 455/126; 455/119

[58] Field of Search 455/126, 110, 455/119, 113, 112

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Primary Examiner—Reinhard J. Eisenzopf

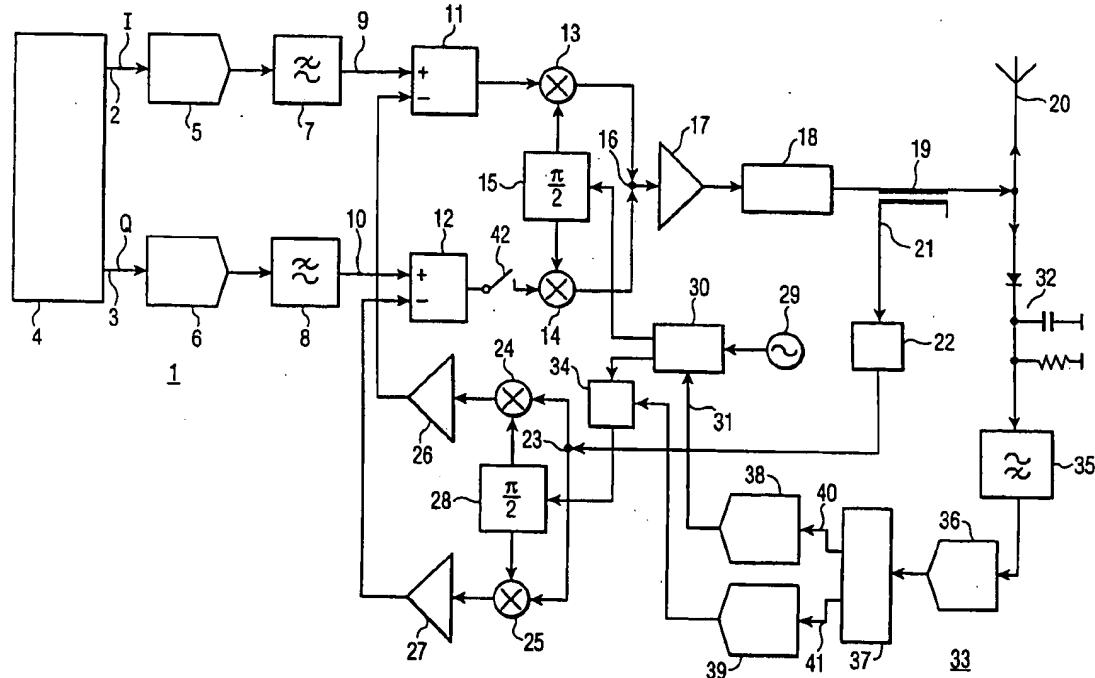
Assistant Examiner—Raymond B. Persino

Attorney, Agent, or Firm—Dicran Halajian

## ABSTRACT

A circuit having a Cartesian amplifier is disclosed. The Cartesian amplifier includes a re-combining stage which re-combines an input signal from a signal source with a correction signal to output a result signal. A first mixer mixes the result signal with a first oscillating signal from a local oscillator. A power amplifier amplifies the mixed signal and a coupler couples part of the amplified signal to form an outcoupling signal. A feedback path has a second mixer for forming the correction signal by mixing the outcoupling signal with a second oscillating signal from the local oscillator. An envelope curve detector detects the envelope of the amplified signal to produce an envelope signal, and a phase adjustor adjusts the phase of the first or second oscillating signal. A control circuit is provided to control the phase errors in a phase locked loop of the Cartesian amplifier and to minimize the envelope signal. The control circuit receives the envelope signal and has an adjustment output for providing an adjusting signal to the phase adjustor. The control circuit further has a modulation output to produce a measuring oscillation signal. A modulation stage modulates the phase position of one of the oscillating signals with the measuring oscillation signal.

8 Claims, 4 Drawing Sheets



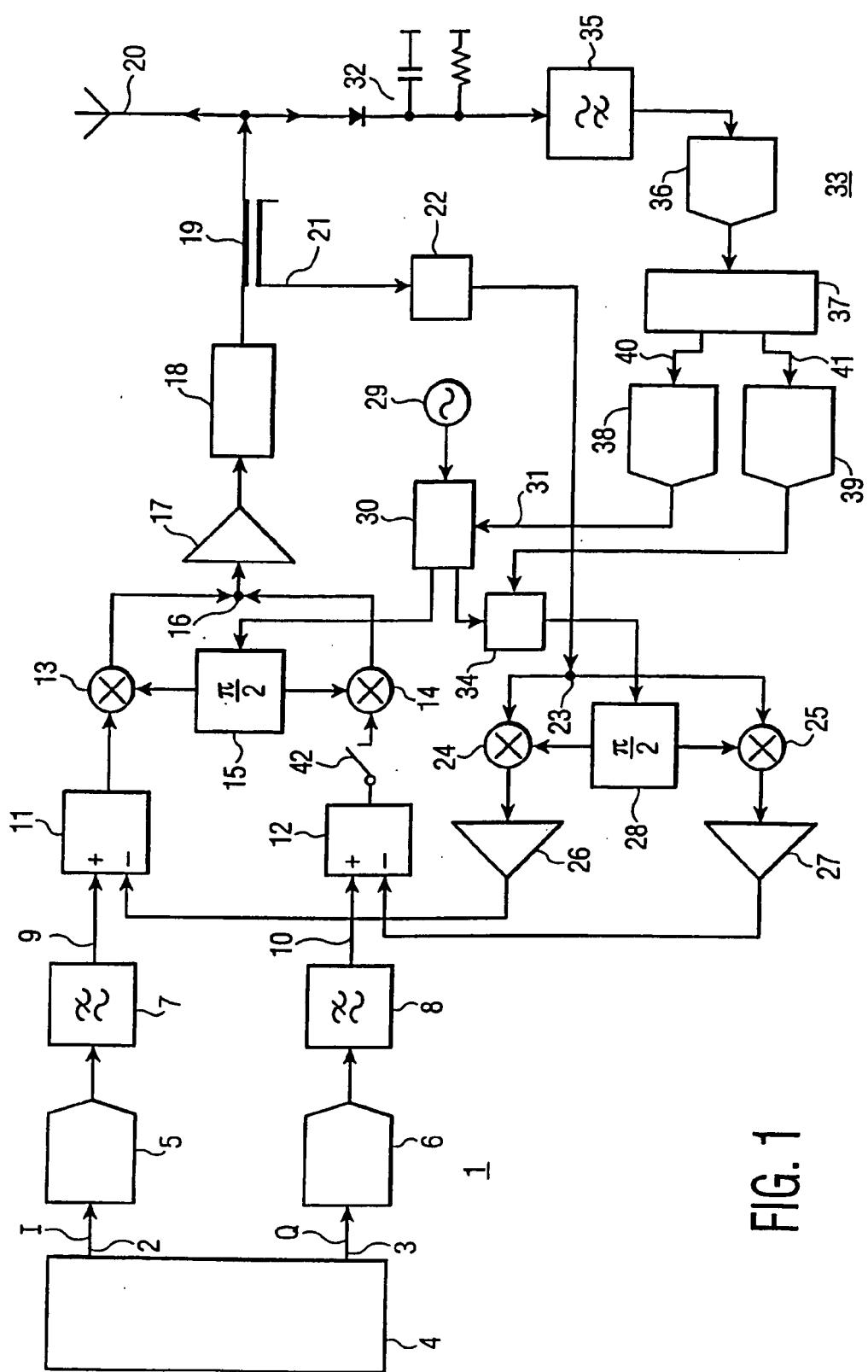


FIG. 1

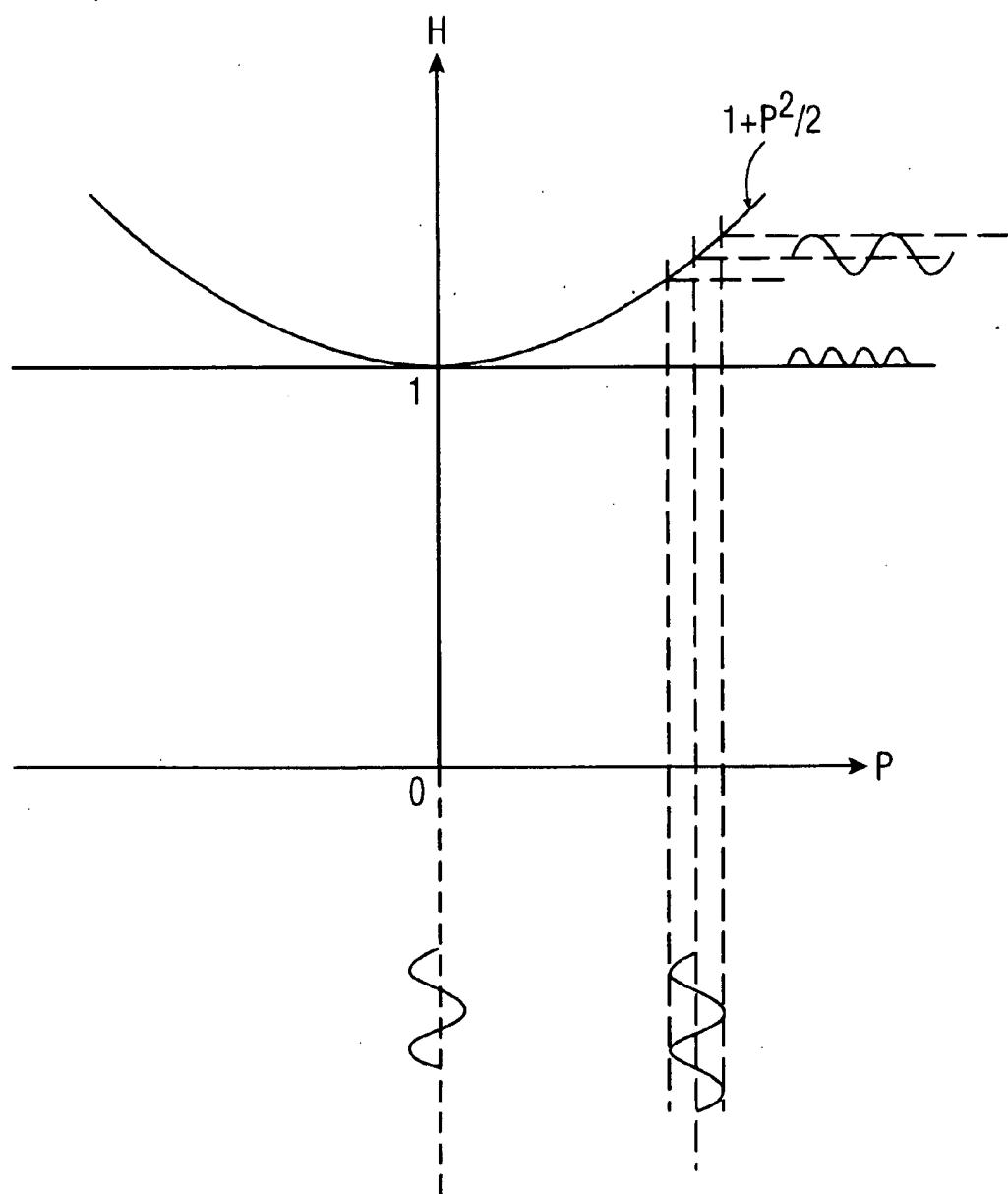


FIG. 2

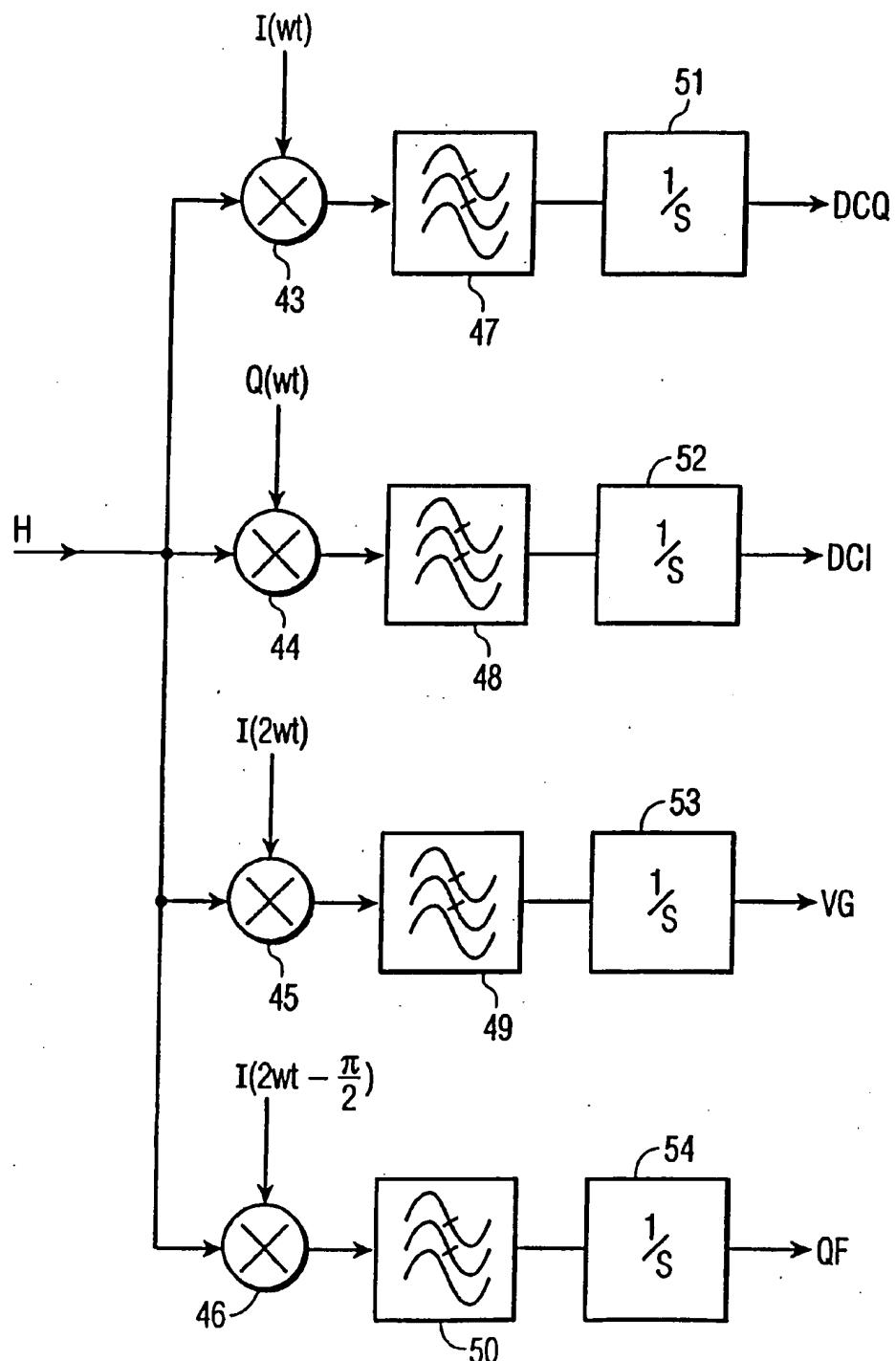


FIG. 3

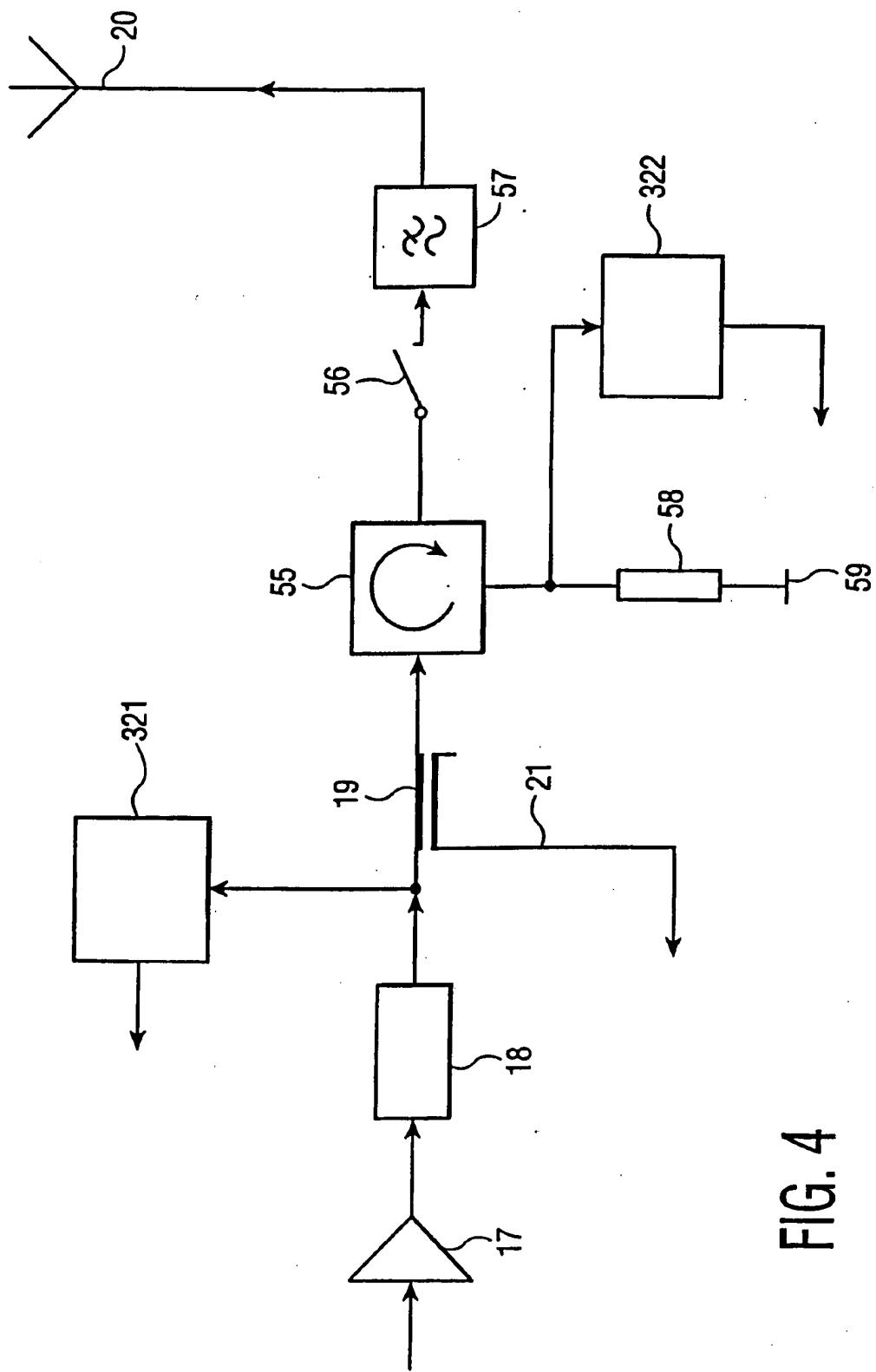


FIG. 4

## CIRCUIT ARRANGEMENT COMPRISING A CARTESIAN AMPLIFIER

### BACKGROUND OF THE INVENTION

The invention relates to a circuit arrangement comprising a Cartesian amplifier, including a signal source for producing an input signal, a re-combining stage for forming a result signal by re-combining the input signal and a correction signal, a first mixer stage for mixing the result signal with a first oscillation of the local oscillator, a power amplifier stage for amplifying the signal produced by the first mixer stage, a coupler for coupling out part of the output signal of the power amplifier stage as an outcoupling signal, a feedback path comprising a second mixer stage for deriving the correction signal from the outcoupling signal by mixing the outcoupling signal with a second oscillator of the local oscillator, an envelope curve detection stage for producing an envelope curve signal which corresponds to the envelope curve of the output signal of the power amplifier stage, and a phase adjustment stage for adjusting the phase position of at least one of the oscillations of the local oscillator.

The invention further relates to a transmitter apparatus comprising a circuit arrangement of said type and to mobile radio equipment comprising such a transmitter apparatus.

Such a Cartesian amplifier is known from European Patent Application 598 585. In that Application, an input signal is preprocessed and split into two mutually orthogonal signal components (quadrature components). The two quadrature components are passed, in parallel, through associated signal paths of an error amplifier, after which they are re-combined and up-converted to a RF band. The output signal of the amplifier is utilized to provide a feedback signal. This feedback signal is down-converted from the high-frequency band to the baseband and resolved into two quadrature components. These quadrature components are fed to respective inputs of the error amplifier. The preprocessor for the input signal is periodically switched into a calibration mode in which test signals are applied to the amplifier instead of the input signal. At these times the signal strength of the output signal of the power amplifier is measured and used to provide predistortion factors in the signal preprocessor to improve amplifier linearity.

### OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the invention to provide a simple arrangement for an accurate control of phase errors in the Cartesian loop.

According to the invention this object is achieved with a circuit arrangement of the type defined in the opening paragraph, by

- a control circuit having
  - an input for receiving the envelope curve signal,
  - an adjustment output, from which an adjusting signal for adjusting the phase position of at least one of the oscillations of the local oscillator is applied to the phase adjustment stage, and
  - a modulation output for producing a measuring oscillation,
  - and a modulation stage for modulating the phase position of one of the oscillations of the local oscillator with the measuring oscillation,

which control circuit minimizes from the envelope curve signal the signal portion that results from the modulation with the measuring oscillation, by adjusting the phase position of at least one of the oscillations of the local oscillator by means of the adjusting signal.

Cartesian amplifiers are preferably used as power amplifiers in transmitter devices in which high linearity of the amplification is desired, to avoid distortions of the transmit signal. Such a transmitter device comprising a Cartesian amplifier or a Cartesian loop (so defined after the feedback of the quadrature components) is also shown in the document EP 0 598 585 A2. This Cartesian amplifier has, in essence, four important operating parameters: the phase of the feedback loop, the gain balance between the quadrature components, the quadrature error between the quadrature components, and the carrier remainder. These four operating parameters of the Cartesian amplifier can basically be measured with a single envelope curve detector (envelope curve rectifier) and controlled to achieve optimum operation. The envelope curve rectifier—with the object of the present invention, the envelope curve detector—is connected to the output of the transmitter or of the power amplifier used therein, whose characteristic is to be linearized. After respective filtering, the envelope curve signal delivered by the envelope curve detector represents a direct magnitude of the instantaneous amplitude of the envelope curve of the high-frequency oscillation produced by the power amplifier. Monitoring this envelope curve signal provides the possibility to measure aforesaid four operating parameters of the Cartesian amplifier and readjust them. For this purpose, the invention describes a highly simple and effective arrangement for controlling the phase of the feedback loop.

In a particular embodiment, the control circuit of the circuit arrangement according to the invention comprises a high-pass filter connected to its input for resolving the signal part from the envelope curve signal, which signal part results from the modulation with the measuring oscillation. This high-pass filter can suppress particularly a DC component in the envelope curve signal, thus making a precise evaluation possible of AC parts of the envelope curve signal, even when these AC parts have a smaller amplitude than the DC part.

Preferably, the control circuit comprises an analogue to digital converter for sampling the envelope curve signal. Generation of the measuring oscillation derivation of the adjusting signal may be done using a digital signal processor and a digital analogue converter.

According to another embodiment of the invention, the envelope curve signal is at the same time used for controlling the aforesaid further operating parameters, or adjusting operations for these operating parameters of the Cartesian amplifier. The use of the circuit arrangement according to the invention is then possible without additional circuitry and cost.

According to a further embodiment of the invention, the measuring oscillation is produced during a predefinable time interval in which the signal source produces an input signal with a predefined time variation, and, outside this time interval, the adjusting signal value reached in this same time interval is maintained by the control circuit. Preferably, one of the signal paths for one of the quadrature components in the Cartesian amplifier can be interrupted for this measurement. As a result, this signal path does not contribute to the signal amplified in the power amplifier. In the second signal path, an input signal having a constant value can be transmitted in this time interval. The optimum loop phase parameter is determined in said time interval and then retained by the control circuit at the next operation when a valid signal

is transmitted through the Cartesian amplifier, so that optimum transmission conditions are achieved.

A circuit arrangement according to one of the embodiments of the invention may preferably be used in a transmitter apparatus and within mobile radio equipment comprising such a transmitter apparatus.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

#### BRIEF DESCRIPTION OF THE DRAWING

In the drawings:

FIG. 1 shows an illustrative embodiment of the invention,

FIG. 2 shows a diagram for explaining the circuit arrangement shown in FIG. 1,

FIG. 3 shows a first modification of the illustrative embodiment shown in FIG. 1, and

FIG. 4 shows a second modification of the illustrative embodiment shown in FIG. 1.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The circuit arrangement shown in FIG. 1 comprises a signal source 1 for producing an input signal, which input signal is rendered available in the form of two quadrature components I, Q. These quadrature components I, Q are provided on two respective outputs 2, 3 of a digital modulator 4 and applied each to a digital/analog converter 5, 6, respectively. The signals recovered from the quadrature components I, Q in the digital/analog converters 5, 6 are subsequently led through low-pass filter 7, 8 respectively and are rendered available on the low-pass filter outputs 9, 10 as analog quadrature components of the input signal of the signal source 1. In the present illustrative embodiment, the signal source 1 thus not only comprises the digital modulator 4, but also the digital/analog converters 5, 6 and the low-pass filter 7, 8.

From the output 9, 10, the quadrature components of the input signal are applied to non-inverting inputs of respective differential stages 11, 12 which together form a re-combining stage. The differential stages 11, 12 further have each an inverting input to which a quadrature component of a correction signal can be applied. In the differential stages of the re-combining stage a result signal is formed from the input signal and the correction signal by re-combining them component by component, and quadrature components of this result signal are provided on outputs of the differential stages 11, 12.

The quadrature components of the result signal are applied from the re-combining stage 11, 12 to a respective mixer 13, 14 of a first mixer stage. In the mixers 13, 14, the quadrature components of the result signal are mixed with two wave trains of a first oscillation of the local oscillator, phase shifted through 90° relative to each other by a phase shifter 15, and up-converted in the present embodiment. The quadrature components of the result signal, up-converted in this manner, travel from the mixers 13, 14 of the first mixer stage to a re-combining junction 16 at which said quadrature components are additively re-combined. The thus formed signal reaches a power amplifier stage 18 via a drive amplifier 17. The amplified signal is applied via a coupler 19 to the predominant part of an antenna 20 and radiated thereby.

The coupler 19 formed, for example, by a directional coupler, has an output 21 on which part of the output signal

of the power amplifier 18 is provided as an outcoupling signal. This outcoupling signal from output 21 of the coupler 19 is applied to a feedback path for a derivation of the correction signal which is applied to the inverting inputs of the differential stages 11, 12 in the form of two quadrature components. For this purpose, the feedback path comprises an attenuator 22 for reducing the outcoupling signal (in so far as this reduction has not already been effected by appropriate power division in the coupler 19), a signal divider junction 23, two mixers 24, 25 forming a second mixer stage, and two driver amplifiers 26, 27. From the attenuator 22, the reduced outcoupling signal in the feedback path reaches, via the signal divider junction 23, the two mixers 24, 25 of the second mixer stage in-phase, in which mixers the outcoupling signal is remixed with two 90° phase-shifted wave trains of a second oscillation of the local oscillator, in the present example down-converted by the same frequency value as the result signal was up-converted in the first mixer stage 13, 14. The purpose of the driver amplifiers 26, 27 is to adapt the amplitude between the input signal and the correction signal and these amplifiers may be omitted, as appropriate. The wave trains of the second oscillations of the local oscillator phase shifted by 90° are recovered from these signals in a second phase shifter 28. The two oscillations of the local oscillator are derived from a local oscillator 29. The latter is thereto connected to a phase adjuster 30 in which the two oscillations of the local oscillator are derived from the waveform produced by the local oscillator 29 and the phase position of at least one of the oscillations of the local oscillator is adjusted by an adjusting signal which is applied to the phase adjuster 30 through an adjusting input 31. From two outputs of the phase adjuster 30, the first oscillation of the local oscillator is applied to the phase shifter 15 and the second oscillation of the local oscillator to the second phase shifter 28.

According to the invention, the circuit arrangement shown in FIG. 1 further includes an envelope curve detector 32, a control circuit 33 as well as a modulator 34. The envelope curve detector 32 is used in known manner for providing an envelope curve signal which corresponds to the envelope curve of the output signal of the power amplifier 18. The control circuit 33 comprises a high-pass filter 35 downstream of the envelope curve detector 32, an analog/digital converter 36, a digital signal processor 37 comprising digital means for evaluating the envelope curve signal, and two further digital/analog converters 38 and 39. The digital signal processor 37 is connected with its input to the envelope curve detector 32 via the analog/digital converter 36 and the high-pass filter 35; a first output 40 of the digital signal processor 37 is connected to the adjusting input 31 of the phase adjuster 30 via the digital/analog converter 38, while a second output 41 of the digital signal processor 37 is connected to the modulation stage 34 via the digital/analog converter 39.

The operation of the control circuit 33 and the modulation stage 34 will be further explained with reference to the diagram shown in FIG. 2. If the signal path for one of the quadrature components of the result signal (and thus of the input signal) in the represented Cartesian loop is interrupted in the circuit arrangement shown in FIG. 1, the effective feedback loop gain will be changed by the appearance of a phase error in the feedback loop. More particularly, the gain of the feedback path (22-27 in FIG. 1) will become dependent on the cosine of the phase error P of the feedback loop. The output amplitude of the power amplifier 18 of the antenna 20, and thus of the circuit arrangement of FIG. 1 is proportional to the reciprocal value of the gain of the

feedback loop, so that the amplitude of the signal produced by the power amplifier 18 will become inversely proportional to the cosine of the phase error  $P$  of the feedback loop. Thus, for a predefined excitation of the Cartesian amplifier caused by a certain input signal, the smallest power level will appear when the phase of the feedback loop is adjusted to its correct value, when the phase error  $P$  of the feedback loop becomes zero.

These facts are utilized by the invention to regulate the phases of the feedback loop to their correct value. For this purpose, the envelope curve signal, produced by the envelope curve detector 32, can be simply minimized by adjusting the phase of the feedback loop. When this minimum is reached for the envelope curve of the carrier oscillation (FIG. 1: First oscillation of the local oscillator), the phase of the feedback loop is adjusted correctly.

In practice, it appears that for the envelope curve detector 32 and the control circuit 33 it is necessary to have a very high amplitude resolution, because the maximum permissible value for the phase error  $P$  of the feedback loop only leads to minor changes in the signal amplitude on the output of the power amplifier 18 and thus in the envelope curve signal (referenced  $H$  in FIG. 2). For example, a  $5^\circ$  phase error  $P$  of the feedback loop produces an increase of the envelope curve signal  $H$  by only 0.38%. Especially in the audio/digital converter 36 in FIG. 1, a high resolution is necessary for a direct sampling of the envelope curve signal  $H$  to measure the resulting amplitude changes accurately enough.

According to the invention, for adjusting the phase of the feedback loop, this phase is modulated by a certain value around its normal value. If the nominal value i.e. the feedback loop phase value that has just been adjusted, as it appears in FIG. 1 particularly from the phase regulator as it is adjusted by the adjusting signal on input 31, is erroneous, said modulation of the phase of the feedback loop will take place via an amplitude modulation of the envelope curve of the output signal of the power amplifier 18, and thus via an amplitude modulation of the envelope curve signal  $H$ . The modulation depth is then directly proportional to the phase error  $P$  of the feedback loop, and this can be directly measured by evaluating the envelope curve signal. As this necessitates the evaluation of the AC component of the envelope curve signal, advantageously only an AC coupling is effected from the envelope curve detector 32 to the control circuit 33. In the illustrative embodiment shown in FIG. 1, the high-pass filter is used therefor. This filter does away with the necessity of resolving slight differences in DC current levels, so that changes of the envelope curve signal  $H$  can be detected. As a result, the requirements as to circuitry of the analog/digital converters are kept within boundaries.

The amplitude of the envelope signal  $H$  having the frequency of the above-mentioned modulation of the phase of the feedback loop is directly proportional to the mean value of the phase error  $P$  of the feedback loop when averaged over a period of this phase modulation. When the phase error  $P$  of the feedback loop becomes zero, the envelope curve detector 32 will produce a signal at twice the frequency of the modulation when the above-mentioned phase modulation frequency (frequency with which the phase is modulated for above measuring purposes) is used. This can easily be detected from the diagram in FIG. 2, which shows in standardized form the envelope curve signal  $H$  above the phase error  $P$  of the feedback loop for the Cartesian amplifier shown in FIG. 1. As is described, the envelope curve signal  $H$  is inversely proportional to the

cosine of phase error  $P$  of the feedback loop. For small values of  $P$ , this reciprocal value of the cosine function can be approximated by the function  $1+P^2/2$  shown. This expression becomes 1, if  $P$  becomes zero. The relative standarized rise of amplitude of the envelope curve signal  $H$  is thus approximately  $P^2/2$ . The square-law variation of this function means that for slight variations of the phase of the feedback loop according to the modulation described above, the value of the amplitude modulation generated thereby rises linearly with the phase error  $P$  of the feedback control. This is because the rise of the square-law function is directly proportional to  $P$ .

This fact can also be made use of for adjusting the phase of the feedback loop automatically by a simple control loop which includes the envelope curve detector 32. The square-law dependence of the envelope circuit signal  $H$  on the phase error  $P$  of the feedback loop means that the phase of the envelope curve signal for positive loop phase errors is different from the phase for negative loop phase errors. When comparing the phase of the envelope curve signal  $H$  with the phase of the modulation signal with which the phase of the feedback loop is modulated, there may be directly established that the phase error  $P$  is either positive or negative. Such a phase comparison may be effected in an analog multiplier, or by digital means, for example, the digital signal processor 37 in the control circuit 33. The result of this comparison may then be used for controlling the nominal phase of the feedback loop. Preferably, this control loop may comprise an intergrator or an integrating control function to ensure that the loop settles with a zero error.

In FIG. 1, the digital signal processor 37 is used for generating a digital measuring signal on its second output 41, from which signal analog measuring oscillation is formed in the subsequent digital/analog converter 39. The output of the digital/analog converter 39 forms a modulation output from which the measuring oscillation is applied to the modulator 34. In the modulator 34, the phase position of the second oscillation of the local oscillator, on its way from the phase adjustor 30 to the second phase shifter 28, is modulated in the described manner with a predefined frequency (with the frequency of the measuring oscillation) by a predefined value. The resulting amplitude modulation of the envelope curve signal is evaluated by the digital signal processor 37 (applied through the analog/digital converter 36). In accordance with the rules described, the digital signal processor 37 generates a digital adjusting signal on its first output 40, which signal is converted in the subsequent digital/analog converter 38 into an analog adjusting signal. The output of the digital/analog converter 38 thus forms an adjusting output of the control circuit 33. The analog adjusting signal is applied from this adjusting output to the adjusting inputs 31 of the phase adjustor 30. In the phase adjustor 30 the adjusting signal adjusts the phase of at least either oscillation of the local oscillator. For example, only the first or the second oscillation of the local oscillator can be adjusted, but the two may also be adjusted in opposite directions etc.

FIG. 2 shows two cases of a modulation of the phase of the feedback loop. In the first case, the phase is modulated by a nominal value which is situated  $P=0$ . Accordingly, there is no or substantially no modulation of the envelope curve signal  $H$  at the loop phase modulation frequency. In the second case, a non-zero phase error  $P$  of the feedback loop occurs. If the phase of the feedback loop is modulated around this value, the result will be a modulation of the envelope curve signal  $H$ .

The measuring oscillation is preferably generated during a predefinable time interval in which the signal source 1

produces an input signal with a predefined time delay. During this time interval, a switch 42 interrupts, preferably in the circuit arrangement shown in FIG. 1, the signal path for the quadrature components Q of the result signal between the differential stage 12 and the mixer 14. During operation, when a valid signal travels from the signal source 1 to the antenna 20, the switch is conductive. The phase value of the feedback loop reached during second time interval is stored in this digital signal processor 37 for the operation with the valid signal i.e. the value reached for the digital adjusting signal is stored. 10

In addition to the described phase control of the feedback loop, the envelope curve signal H may also be used as a measuring signal for controlling the gain balance VG, the quadrature error QF and the DC shift DCQ or DCI respectively, which result from carrier residual in the quadrature components of the signal to be amplified in the Cartesian amplifier. Since all these measuring quantities are orthogonal to each other in terms of high-frequency measurements, they may be recovered simultaneously from one and the same envelope curve signal H. This allows a 20 high speed and efficiency evaluation of the envelope curve signal and thus a high speed adjustment of the Cartesian loop. 15

FIG. 3 shows in a diagram an example for an analog circuit arrangement for multiple evaluation of the envelope 25 curve signal H. This signal is applied to the first inputs of four mixers 43, 44, 45, 46 and mixed therein with oscillations derived from the quadrature components I or Q with the frequency of a test modulation source 37, 39 (FIG. 1) (angular frequency  $\omega$ ) or with twice this frequency, while the 30 oscillations having twice said frequency are phase shifted to each other by  $90^\circ$ . Time is referenced t there.

The consequent oscillations are filtered and subsequently integrated in integrators 51, 52, 53 and 54 by the respective low-pass filters 47, 48, 49 and 50 following the mixers 43 to 46. The measuring quantities are simultaneously available for evaluation on the outputs of the integrators. This evaluation may be effected, for example, in the digital signal processor 37 shown in FIG. 1, so that a high-performance and compact control arrangement arises. The arrangement 40 shown in FIG. 3 may also be designated a coherent detector.

Albeit, according to aforesaid embodiments, only a single envelope curve detector is needed, it may be useful connecting this detector differently to the signal path from the power amplifier 18 to the antenna 20 (or to a comparable 45 signal path at the output of the power amplifier 18). In this respect FIG. 4 shows two embodiments as a modification of a part of the FIG. 1 which, for reasons of simplicity, is represented only as a section. Like elements already described, carry like references. In FIG. 4 is inserted between the coupler 19 and the antenna 20 a circulator 55, a switch 56 and a low-pass filter 57 which has a high limit-frequency for suppressing top oscillations of the transmission frequency (i.e. of the carrier frequency or the frequency of the oscillation of the local oscillator). The 55 switch is used for disconnecting the antenna, as required. A third connection of the circulator 55 is grounded at 59 via a load resistor 58. A first envelope curve detector 321, and a second envelope curve detector 322, parallel with the load resistor 58, are connected to the output of the power amplifier 18. The first envelope curve detector 321 is preferred for a so-called envelope curve feedback, whereas the second envelope curve detector 322 is preferred for a VSWR feedback (VSWR is to be understood to mean Voltage-to-Standing Wave Ratio). One of these envelope curve detectors may preferably be used in an analog control circuit, the other in a digital control circuit as shown in FIG. 1. 60

I claim:

1. A circuit arrangement comprising a Cartesian amplifier, including

- a signal source for producing an input signal,
- a re-combining stage for forming a result signal by re-combining the input signal and a correction signal,
- a first mixer stage for mixing the result signal with a first oscillation of the local oscillator,
- a power amplifier stage for amplifying the signal produced by the first mixer stage,
- a coupler for coupling out part of the output signal of the power amplifier stage as an outcoupling signal,
- a feedback path comprising a second mixer stage for deriving the correction signal from the outcoupling signal by mixing the outcoupling signal with a second oscillation of the local oscillator,
- an envelope curve detection stage for producing an envelope curve signal which corresponds to the envelope curve of the output signal of the power amplifier stage, and
- and a phase adjustment stage for adjusting the phase position of at least one of the oscillations of the local oscillator, characterized by
- a control circuit having
- an input for receiving the envelope curve signal,
- an adjustment output, from which an adjusting signal for adjusting the phase position of at least one of the oscillations of the local oscillator is applied to the phase adjustment stage, and
- a modulation output for producing a measuring oscillation,
- and a modulation stage for modulating the phase position of one of the oscillations of the local oscillator with the measuring oscillation,

which control circuit minimizes from the envelope curve signal the signal portion that results from the modulation with the measuring oscillation, by adjusting the phase position of at least one of the oscillations of the local oscillator by means of the adjusting signal.

2. A circuit arrangement as claimed in claim 1, characterized in that the control circuit comprises a high-pass filter connected to its input for isolating the signal part resulting from the modulation with the measuring oscillation from the envelope curve signal.

3. A circuit arrangement as claimed in claim 1, characterized in that the control circuit comprises digital switching means for evaluating the envelope curve signal and producing the measuring oscillation and the adjusting signal.

4. A circuit arrangement as claimed in one of the preceding claims, characterized in that the envelope curve signal is simultaneously used for controlling further operating parameters and/or tuning operations of the Cartesian amplifiers.

5. A circuit arrangement as claimed in claim 1, characterized in that the measuring oscillation is generated during a predefinable time interval while the signal source produces an input signal with a predefined time delay, and in that outside this time interval the value of the adjusting signal reached in this very time interval is retained by the control circuit.

6. A circuit arrangement as claimed in claim 1, characterized in that the input signal is provided in the form of Cartesian signal components by the signal source and in that the re-combining stage and the mixers have different signal paths for these or associated signal components.

7. A transmitter apparatus comprising a circuit arrangement as claimed in claim 1.

8. Mobile radio equipment comprising a transmitter apparatus as claimed in claim 7.

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US005564087A

United States Patent [19]

Cygan et al.

[11] Patent Number: 5,564,087

[45] Date of Patent: Oct. 8, 1996

[54] METHOD AND APPARATUS FOR A LINEAR TRANSMITTER

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[75] Inventors: **Lawrence F. Cygan, Schaumburg; Paul H. Gailus, Prospect Heights; William J. Turney, Schaumburg, all of Ill.**

[73] Assignee: **Motorola, Inc., Schaumburg, Ill.**

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*Assistant Examiner*—Gertrude Arthur  
*Attorney, Agent, or Firm*—Andrew S. Fuller

[21] Appl. No.: 333,693

[22] Filed: Nov. 3, 1994

[57] ABSTRACT

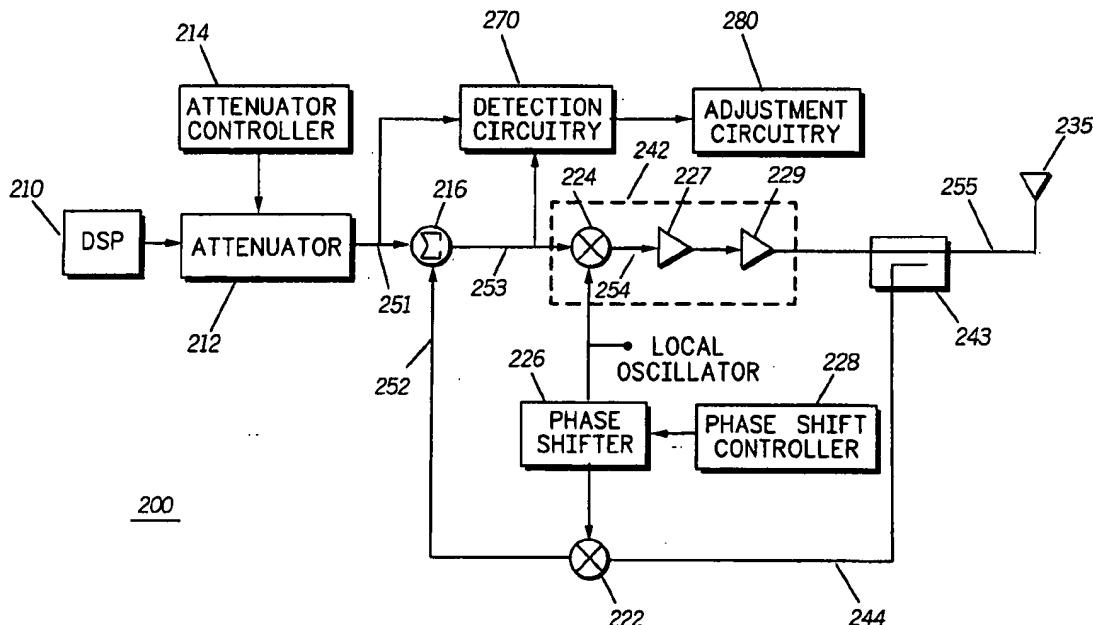
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A method and apparatus is provided for a transmitter (200) with a stable, linear response. The transmitter (200) includes an amplification stage (242), and a negative feedback correction loop (244) with a feedback signal (252). A reference signal (251) is combined with the feedback signal (252) to produce an error signal (253) for coupling to the amplification stage (242). Transmitter parameters are varied when a difference between the reference signal (251) and the error signal (253) exceeds a particular threshold.

**26 Claims, 8 Drawing Sheets**



***FIG.1***

(PRIOR ART)

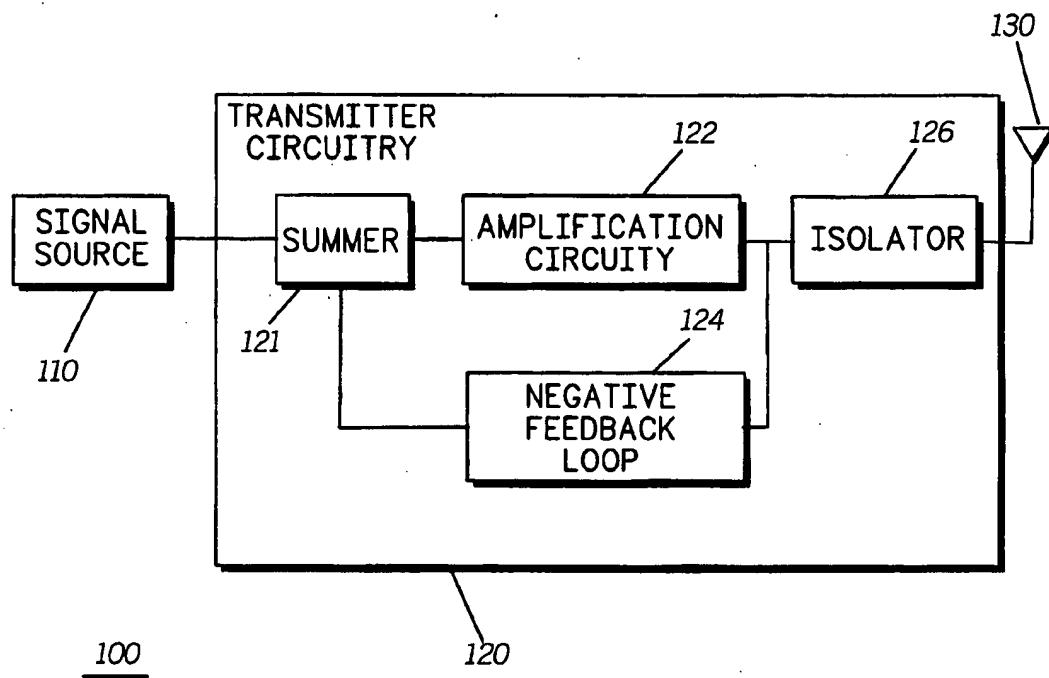


FIG. 2

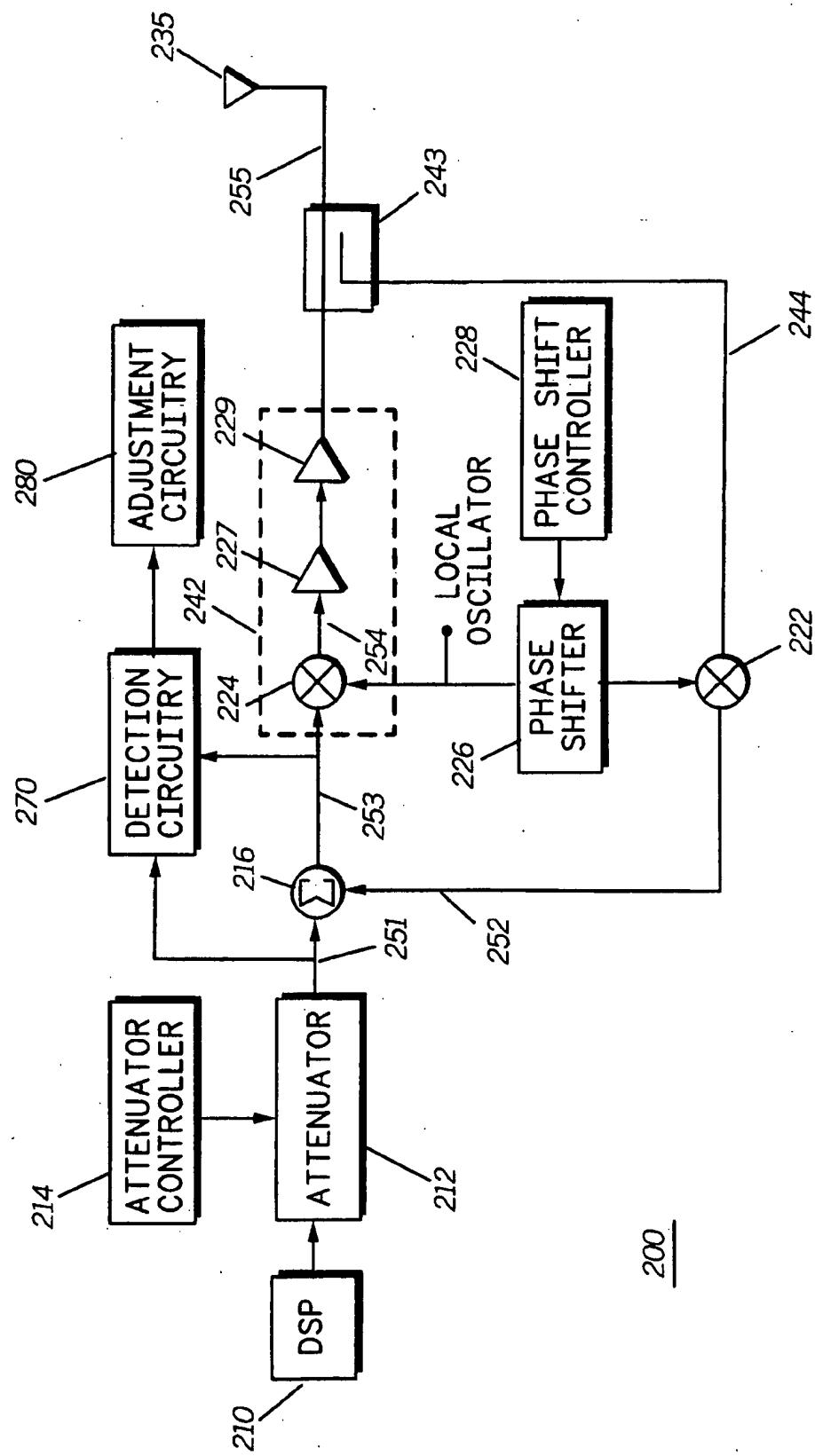


FIG.3

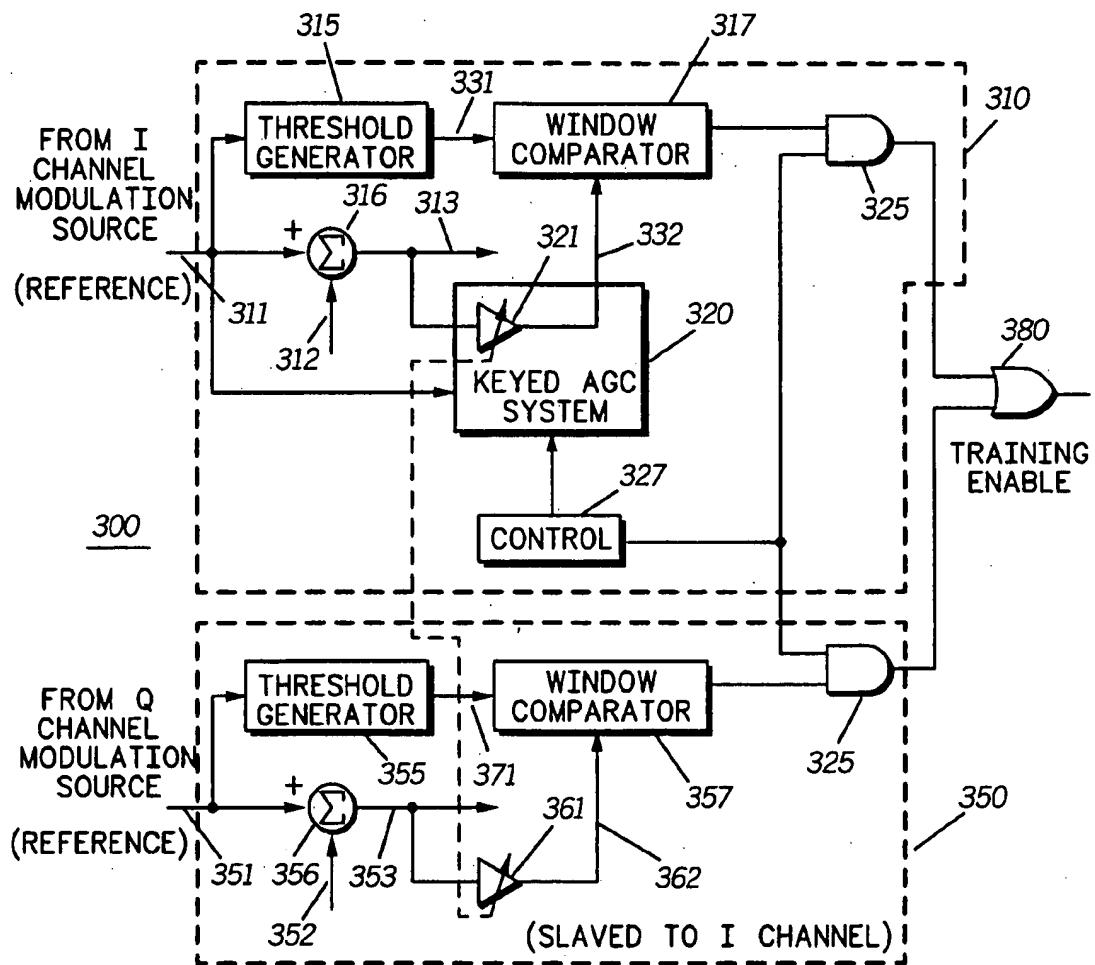


FIG. 4

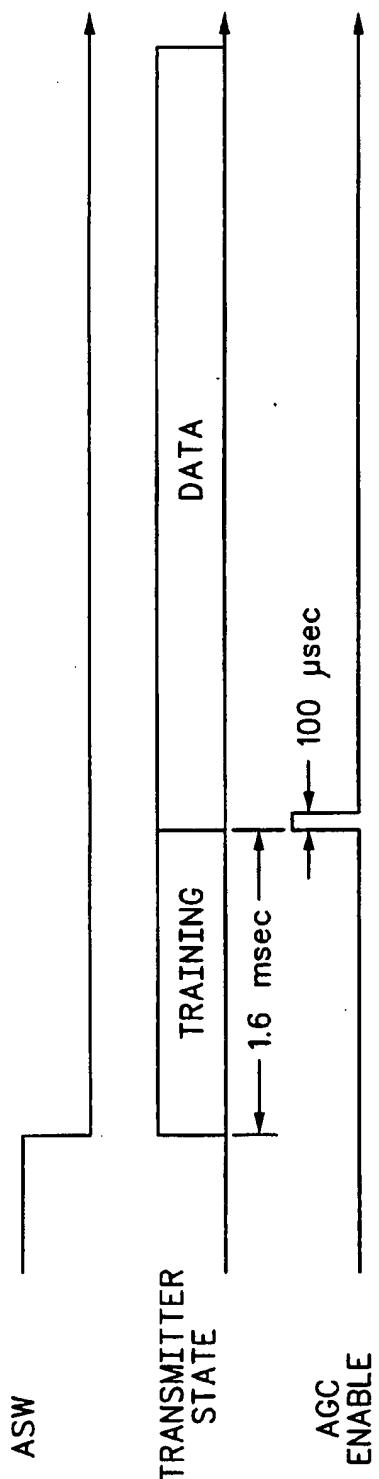
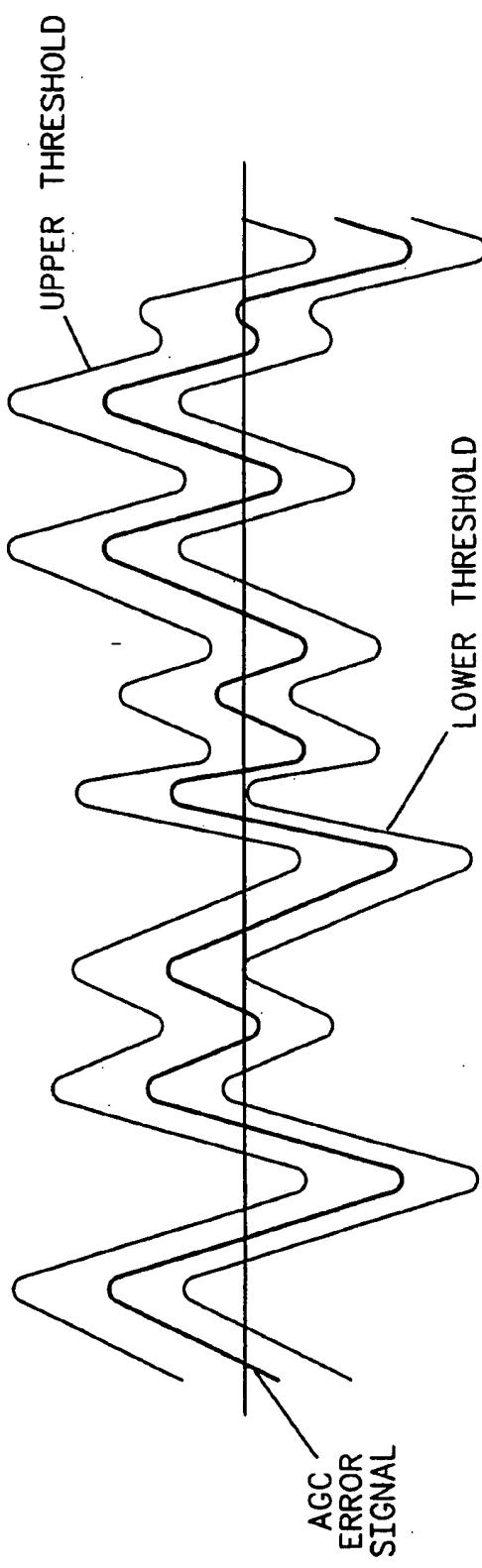
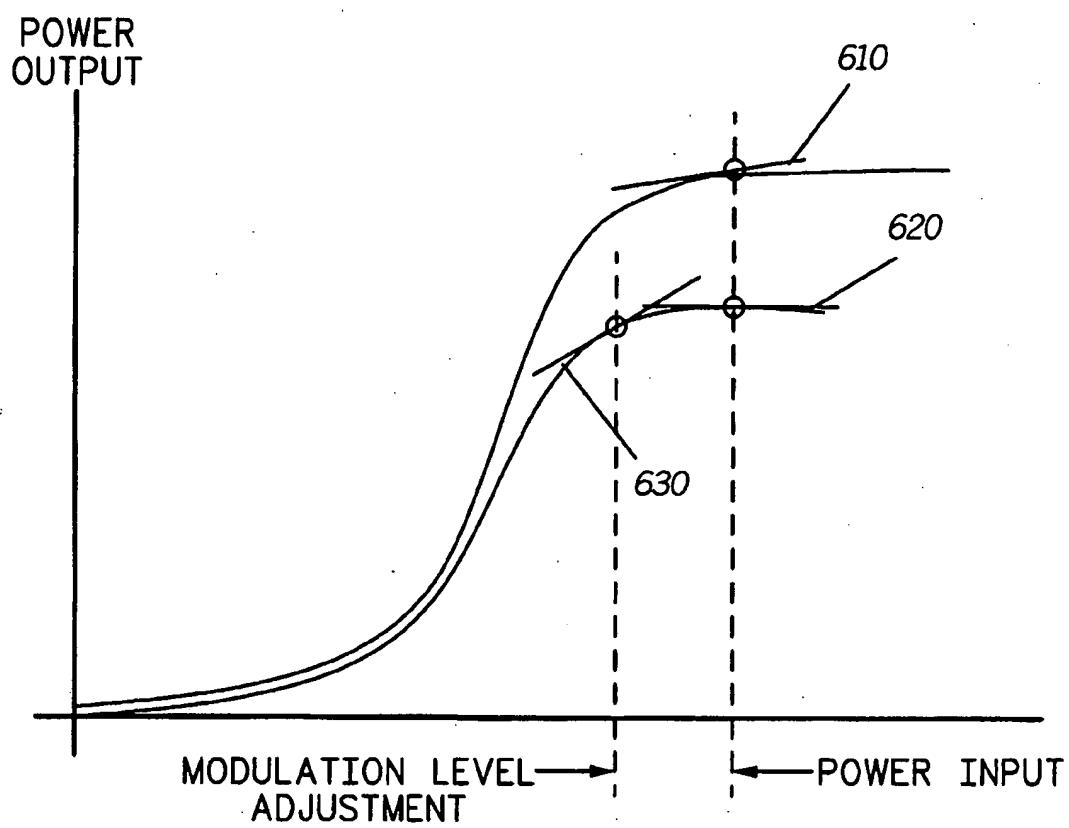


FIG. 5



***FIG. 6***

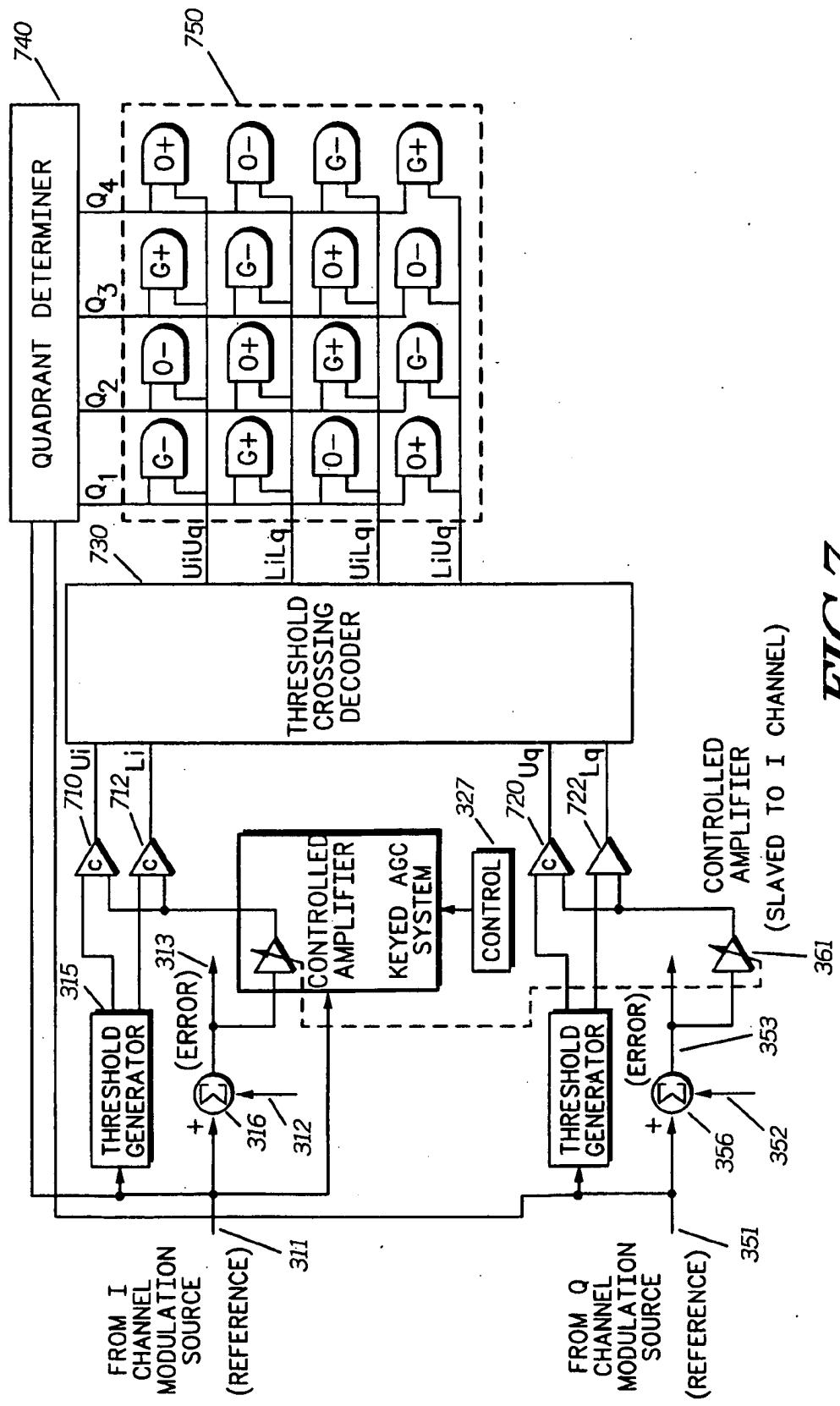
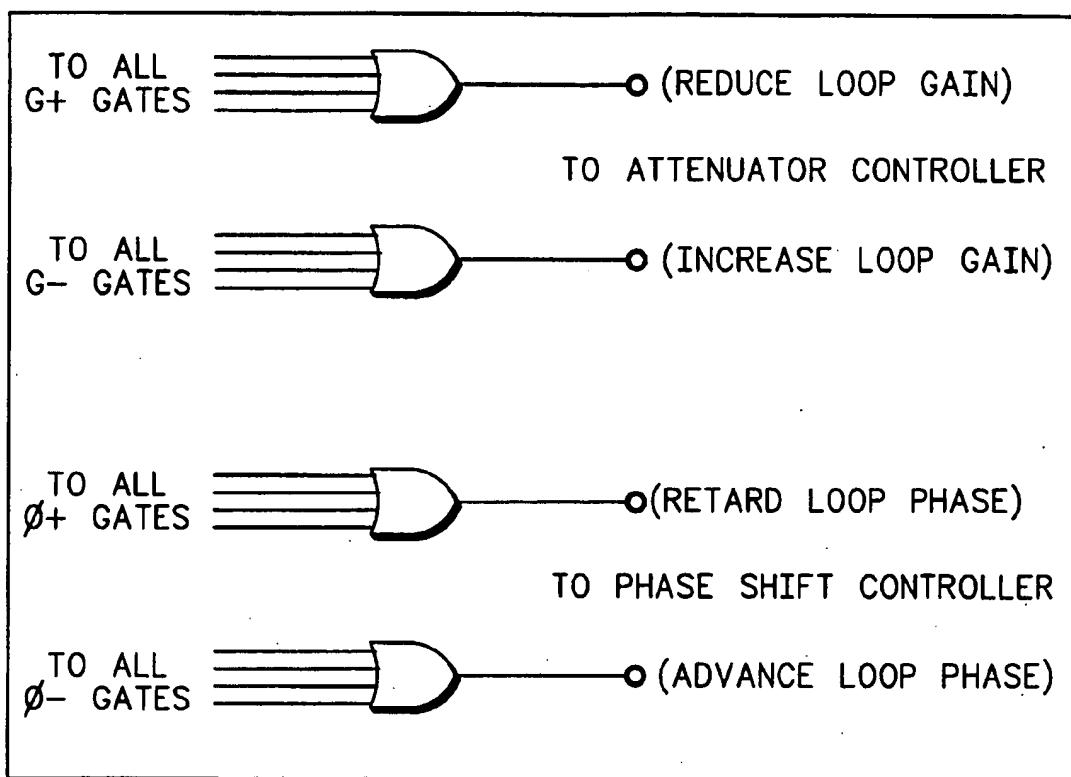
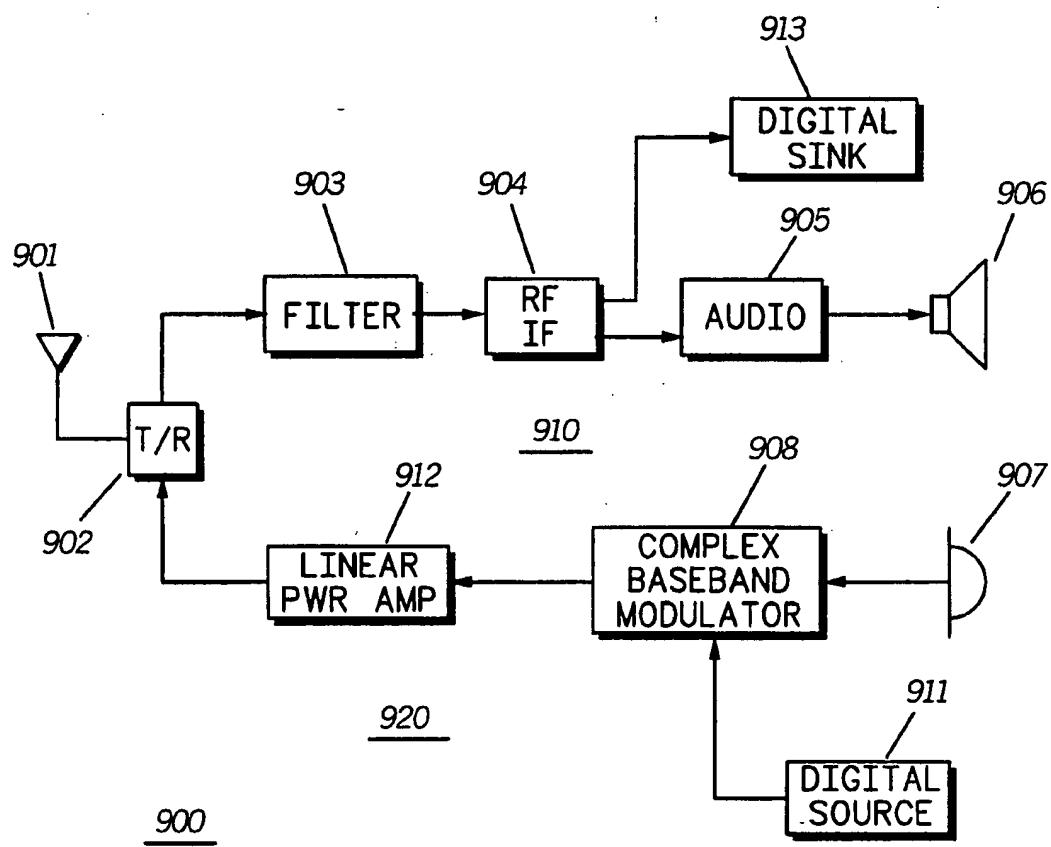


FIG. 7

*FIG.8*

***FIG.9***

**METHOD AND APPARATUS FOR A LINEAR  
TRANSMITTER**

**TECHNICAL FIELD**

This invention relates in general to transmitters, and more particularly, to linear transmitters.

**BACKGROUND OF THE INVENTION**

In a typical radio communication device, a transmitter is coupled to an antenna to provide a transmission path for communication signals. The transmitter includes a power amplifier to amplify the signals before transmission. The behavior of a transmitter may be affected by its operating environment. For example, a transmitter operating near an electromagnetically reflective structure may be susceptible to energy reflected back through the antenna into the transmitter. Reflective energy may be detrimental to transmitter performance, particularly to the performance of the power amplifier. The power amplifier design often relies upon a constant load impedance in maximizing gain, efficiency, power output level, and other like parameters. To protect against changes in load impedance as a result of reflected energy, an isolator is often inserted between the antenna and the power amplifier of a transmitter in order to protect the power amplifier from reflected energy. The isolator directs the reflected energy to an absorptive load termination. Although the isolator generally works well, the isolator adds significant cost, size, and weight to the design of a radio communication device.

Another prior art solution to the problem of reflected energy incorporates a directional coupler to detect the reflected energy and adjusting the gain of the power amplifier accordingly. Generally, to minimize the potential of damage to the power amplifier, the gain to the power amplifier is reduced when high levels of reflected energy are present. Directional couplers and associated circuitry also add cost and complexity to a radio design.

FIG. 1 is a block diagram showing a prior art linear transmitter 100. Linear transmitters, which are typically used in quadrature amplitude modulation (QAM), must provide a predictable response in order to reliably transmit complex base band signals. In the linear transmitter 100, a signal source 110 provides a complex baseband signal to transmitter circuitry 120. Amplification circuitry 122 amplifies the signal for transmission through an antenna 130. As is typical in the prior art, a feedback signal from a negative feedback correction loop 124 is combined with the source signal in a summer 121. The feedback loop is used to improve the linearity of the power amplifier. In so doing, the level of energy transmitted on adjacent channel frequencies, known as splatter, is reduced. Such adjacent channel energy may be disruptive to negative feedback correction. Further included in the prior art transmitter 100 is an isolator 126 situated between the antenna 130 and the remaining transmitter circuitry.

The isolator presents a constant load impedance to the power amplifier irrespective of the impedance presented to the isolator by the antenna. The use of the isolator thereby avoids unpredictable variations in power amplifier gain and phase characteristics which would occur if the antenna were connected directly to the power amplifier. Those skilled in the art will understand that a varying load impedance will cause the power amplifier gain to change, thus altering the effectiveness of the feedback correction loop. Such load

variations may also result in phase changes within the power amplifier which may make the feedback loop unstable. Unstable operation may result in severe interference to other communication services and/or the destruction of the linear transmitter. Thus, the isolator protects the power amplifier from load impedance changes and associated reflected energy from the antenna 130 during the transmission.

It is desirable to provide a linear transmitter while avoiding the cost, size, and weight issues associated with isolators. Such linear transmitters must be capable of rapidly adjusting to changes in operating environment to maintain a stable, linear response.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a block diagram showing a prior art linear amplifier.

FIG. 2 is a linear transmitter in accordance with the present invention.

FIG. 3 shows circuitry for implementing detection of changes within the linear transmitter of FIG. 2, and adjustments thereof, in accordance with the present invention.

FIG. 4 is a timing diagram showing the activation of an automatic gain control system for the purpose of scaling an error signal, in accordance with the present invention.

FIG. 5 is a graph depicting the threshold envelope for the scaled error signal, in accordance with the present invention.

FIG. 6 is a graph depicting power amplifier transfer characteristics under different antenna loads, in accordance with the present invention.

FIG. 7 is an alternative embodiment for implementing detection and adjustment of operating characteristics of the linear transmitter of FIG. 2, in accordance with the present invention.

FIG. 8 highlights implementation of corrective actions corresponding to the embodiment of FIG. 7.

FIG. 9 is a block diagram of a communication device incorporating the linear transmitter of FIG. 2, in accordance with the present invention.

**DETAILED DESCRIPTION OF THE  
PREFERRED EMBODIMENT**

While the specification concludes with claims defining the features of the invention that are regarded as novel, it is believed that the invention will be better understood from a consideration of the following description in conjunction with the drawing figures, in which like reference numerals are carried forward.

Referring now to FIG. 2, a linear transmitter 200 is shown in accordance with the present invention. A digital signal processor (DSP) 210 represents a signal source which provides an input signal to a variable attenuator 212. The input signal is a complex digital baseband signal having quadrature components, i.e., in-phase and quadrature signal components. The attenuator 212 provides a modulated reference signal 251 which is coupled to a summing junction 216. The summing junction 216 sums or combines a feedback signal 252 and the reference signal 251 to provide an error signal 253 as input to an amplification stage or circuitry 242. The amplification stage includes an up converter or mixer 224 to translate the modulated baseband signal to the required radio frequency (RF) for transmission as determined by the frequency of a local oscillator. A gain stage 227 amplifies the frequency translated signal and provides an input to a RF power amplifier 229 which in turn provides an RF output

signal 255. In a negative feedback correction loop 244, the RF output signal is sampled by a directional coupler 243 and applied to a down converter or mixer 222, thereby returning the radio frequency signal to the baseband frequency. The output of the mixer 222 is the feedback signal 252. The RF output signal 255 is fed to the antenna 235.

A phase shifter 226, under the control of a phase shift controller 228, is used to set the loop phase such that the feedback signal 252 is effectively subtracted from the reference signal 251 in the summing junction 216. Feedback loop phase is adjusted by controlling the phase of the local oscillator applied to the down converter 222. An attenuator controller 214 controls the level of the modulated reference signals applied to the transmitter circuitry. In a preferred embodiment, attenuation adjustments and phase shift adjustments are provided in conjunction with a training waveform. A detailed description of the training waveform methodology can be found in U.S. Pat. No. 5,066,923, issued to Gailus et al. on Nov. 19, 1991, for a Linear Transmitter Training Method And Apparatus. No further discussion will be presented except to facilitate the understanding of the present invention. The training waveform is normally transmitted at the beginning of a transmission, but may also be transmitted during transmission depending upon the communication protocol. The training waveform provides a test signal for circuitry which adjusts modulation levels and loop phase. Proper attenuator adjustment avoids power amplifier clipping, which is responsible for adjacent channel interference (splatter). Proper loop phase adjustment is necessary to prevent loop instability.

In comparing the linear transmitter 200 of the present invention with those of the prior art, it is significant to note the absence of an isolator between the antenna 235, and the remainder of the transmitter circuitry. The removal of the isolator exposes the amplification circuitry to the full range of impedances which may be present at the antenna 235. In ordinary transmitter usage, these impedances may depart significantly from the impedances represented by the antenna's nominal free space design values. When reflective or absorptive bodies are positioned in close proximity to the antenna, the impedance present at the antenna varies in a complex manner. As amplifier designs are typically premised upon a relatively constant load impedance, when this constant load impedance cannot be guaranteed, appropriate compensation must be made in the transmitter circuitry.

The present invention includes the use of circuitry to detect and compensate for changes in the operating environment of the transmitter in order to maintain linear, stable operation. In the preferred embodiment, detection circuitry 270 and adjustment circuitry 280 are included to detect changes within the transmitter circuitry resulting from changes to its operating environment, and to initiate one or more corrective actions as needed. Corrective actions include adjustments to the attenuation and/or phase of the signals within the transmitter circuitry, i.e., the varying of transmitter parameters. The detection circuitry 270 determines, from the reference signal and the error signal whether, there are sufficient differences between the reference and error signals to warrant adjustments to the circuitry. When the differences are determined to exceed a particular threshold, the adjustment circuitry 280 initiates transmitter parameter adjustments, such as by varying the feedback loop gain or feedback loop phase or other signal within the amplification stage. Alternatively, the training waveform and associated transmitter circuitry adjustments may be exercised. Generally, the attenuator controller 214 and phase shift controller 228 operate to ultimately adjust the gain and phase, respectively, of the feedback loop.

FIG. 3 is a more detailed view of one embodiment of the detection circuitry 270 and the adjustment circuitry 280 of FIG. 2, in accordance with the present invention. In this embodiment, the detection and adjustment circuitry operate in conjunction with the use of a training waveform to set transmitter parameters. Separate circuitry portions 310, 350 process the in-phase and quadrature signal components, respectfully, of the complex baseband reference signal from the attenuator or other signal source. Within the in-phase signal component circuitry 310, a summing junction 316 is coupled to the in-phase signal component 311 of the reference signal (see reference signal 251 of FIG. 2). The summing junction 316 combines the reference in-phase signal component 311 and a corresponding feedback signal 312 to provide an error in-phase signal component 313. The reference signal 311 is coupled to a threshold generator 315 which generates a signal threshold 331. Preferably, the signal threshold 331 has two components, an upper threshold and a lower threshold, which vary from the reference signal by a constant. The threshold generator 315 adds and subtracts a constant offset from the in-phase component of the reference signal to create continuous, variable trip points which form upper and lower threshold boundaries, respectively, for the reference signal. The reference signal 311 is also used as input to set the automatic gain control (AGC) system 320, which is used to scale the error signal 313 for comparison purposes. The AGC system 320 uses a variable amplifier 321 to scale the error signal 313 in order to provide a scaled error signal 332 which corresponds with the reference signal 311 when the linear transmitter is operating in a known, and preferred or optimum state. In the optimum state, the AGC system 320 operates to scale the error signal to correspond directly with the reference signal, such that there is no modulation level differences between the reference signal and the error signal. Generally, the transmitter is placed in a preferred state immediately after training, i.e., when the transmission of the training waveform and associated transmitter circuitry have been completed.

Referring to FIG. 4, a timing diagram depicting the enabling of the AGC system is shown in accordance with the present invention. The AGC system is activated shortly after a training operation is completed within the linear transmitter. For example, the antenna switch line (ASW) goes low, initiating transmission of the training waveform. During the training interval, the training waveform is used to measure and adjust the loop phase. This operation insures the feedback polarity around the loop is negative, producing a subtractive effect at the summing junction. Also, during the training interval, the clip point of the power amplifier is measured and used to determine the attenuation level to be applied to the modulated reference signal. In the preferred embodiment, the training operation takes approximately 1.6 milliseconds. Upon completion of the training operation, the AGC system is activated for a short (typically 100 microseconds window) time period. During the AGC activation window, the AGC monitors the reference signal 311 while adjusting the variable gain amplifier 321 which varies the gain of the error signal to produce the scaled error signal 332. At the conclusion of the AGC window, the gain control voltage applied to the variable gain stage of the amplifier is fixed using a sample and hold technique to maintain the scaled error signal 332. FIG. 5 shows a graph depicting upper and lower threshold signal values generated by the threshold generator 315, and the scaled error signal shortly after the completion of both training and AGC system operations.

In the event of an antenna load change, the power amplifier clip point, insertion phase, or both, will likely

cause the error signal to cross either the upper, lower or both of the thresholds. As an example of a clip point change, FIG. 6 shows a graph of the input versus output characteristic of a power amplifier, and the effect of a load impedance variation on the characteristic. The gain associated with a nominal load is defined by a finite non-zero slope 610. If the modulation level is held constant during the load change, the slope is reduced relative to the nominal load case to that of slope 620. The reduced slope 620 implies a gain reduction. Since the overall feedback loop gain is comprised in part by the power amplifier's contribution, the antenna load change results in a loop gain reduction. The loop gain reduction is realized as an increase in the magnitude of the error signal, which causes the error signal to cross the threshold envelope from the threshold generator. Thus, when the error signal strays outside the threshold envelope, it is an indication that adjustments may be needed within the transmitter. Consequently, the transmitter can be compensated by adjustments to the modulation level and phase of the signals therein to re-establish the power amplifier clip point to that reflected by slope 630.

Referring back to FIG. 3, the scaled error signal 332 is compared against upper and lower boundaries or threshold values represented by the threshold signal 331. The window comparator 317 determines whether to cause an adjustment to the operating characteristics of portions of the transmitter. Generally, an adjustment to the transmitter circuitry occurs by enabling transmission of the training waveform, and subsequent measurement and adjustment of loop gain and loop phase. In one embodiment, adjustments are made to transmitter parameters by causing the attenuator to vary the reference signal, and also by causing a phase adjustment within the feedback correction loop. When training occurs, the control circuitry 327 also interfaces with the keyed AGC system to reset the gain characteristics for the variable gain amplifier 321. The AND-gates 325 are part of the control circuitry which prevent the issuance of a Training Enable signal during the 1.6 millisecond time slot reserved for the training operation, or during the 100 microsecond window during which the AGC system is activated. Without these AND-gates 325, and their connection to the control circuitry, one training operation could generate a request for another training operation in infinite succession. The tandem operation of training and AGC system activation accomplishes at least two desired effects. First, the training operation compensates loop phase and loop gain in response to the antenna load change presented to the power amplifier. Second, the activation of the AGC system resets the detection circuitry in anticipation of future load changes applied to the power amplifier which will require additional compensation.

The circuitry 350 used for the quadrature signal component is similar to the circuitry 310 used for the in-phase signal component. Thus, the reference quadrature signal component 351 is combined with a corresponding feedback signal 352 by a summing junction 356 to provide an error quadrature signal component 353. A threshold generator 355 generates a threshold envelope for use by a window comparator 357 by adding and subtracting a constant from the quadrature component of the reference signal. A variable amplifier 361 scales the error quadrature signal component 353 to produce a scaled error signal 362 which is used as a comparison by the window comparator 357. Preferably, the controller of the variable amplifier 361 is slaved to the control system used in the circuitry 310 for the in-phase single component to reduce circuit complexity. Either of the circuitry 310 for the in-phase signal component or the circuitry 350 for the quadrature signal component may be used to enable training as evidenced by OR-gate 380.

FIG. 7 shows an alternative embodiment in which direct adjustments are made to increase or reduce loop gain, and to retard or advance loop phase, in order to maintain stable, linear operation without the use of training. This provides increased efficiency in the use of a radio or other communication channel as less time is devoted to training, which conveys no information-bearing data. Further, this method acts to identify and compensate for only that transmitter variable that needs adjustment, in contrast to the blanket measure and adjust technique provided by training. Like reference numerals from FIG. 3 are carried forward and only the differences are discussed with respect to FIG. 7.

The window comparators 317, 357 are shown as separate comparators 710, 712 corresponding to the in-phase signal component, and comparators 720 and 722 corresponding to the quadrature signal component. The in-phase signal component comparator 710, 712 outputs  $U_i$  when the in-phase signal component exceeds the upper boundary of the threshold envelope (or upper threshold), and  $L_i$  when the in-phase signal component exceeds the lower boundary of the threshold envelope (or lower threshold). Similarly, quadrature comparators 720, 722 output signals  $U_q$  when the quadrature signal component exceeds the upper boundary of the threshold envelope (or upper threshold), and  $L_q$  when the quadrature signal component exceeds the lower boundary of the threshold envelope (or lower threshold). Signals  $U_i$ ,  $L_i$ ,  $U_q$ , and  $L_q$  are processed by a threshold crossing decoder 730, which determines threshold characteristics.

The threshold decoder determines that at least one of four (4) threshold characteristics exists when  $U_i$  and  $U_q$  ( $U_iU_q$ );  $L_i$  and  $L_q$  ( $L_iL_q$ );  $U_i$  and  $L_q$  ( $U_iL_q$ ); or  $L_i$  and  $U_q$  ( $L_iU_q$ ) are simultaneously present. Additionally, a quadrant determiner 740, using the in-phase and quadrature signal components of the reference signal, determines whether the reference signal falls into a first quadrant (Q1), a second quadrant (Q2), a third quadrant (Q3), or a fourth quadrant (Q4). Signal lines indicating Q1, Q2, Q3, and Q4 are coupled to threshold characteristic lines  $U_iU_q$ ,  $L_iL_q$ ,  $U_iL_q$ , and  $L_iU_q$  in a matrix of AND-gates 750. Based on the combination of quadrant and threshold crossing characteristics, a determination is made whether to reduce or increase loop gain and/or whether to retard or advance loop phase.

FIG. 8 shows the appropriate action for a given combination identified by the AND-gate matrix 750 of FIG. 7. Loop gain is reduced when a first threshold characteristic ( $U_iU_q$ ) exists and the reference signal is in the third quadrant (Q3); the second threshold characteristic  $L_iL_q$  exists and the reference signal is in the first quadrant (Q1); the third threshold characteristic ( $U_iL_q$ ) exists and the reference signal is in the second quadrant (Q2); or the fourth threshold characteristic ( $L_iU_q$ ) exists and the reference signal is in the fourth quadrant (Q4). The loop gain is increased when  $U_iU_q$  exists and the reference signal is in Q1;  $L_iL_q$  exists and the reference signal is in Q3;  $U_iL_q$  exists and the reference signal is in Q4; or  $L_iU_q$  exists and the reference signal is in Q2.

The loop phase is retarded when  $U_iU_q$  exists and the reference signal is in Q4;  $L_iL_q$  exists and the reference signal is in Q2;  $U_iL_q$  exists and the reference signal is in Q3; or  $L_iU_q$  exists and the reference signal is in Q1. The loop phase is advanced when  $U_iU_q$  exists and the reference signal is in Q2;  $L_iL_q$  exists and the reference signal is in Q4;  $U_iL_q$  exists and the reference signal is in Q1; or  $L_iU_q$  exists and the reference signal is in Q3. Preferably, loop gain or reduction is accomplished by varying the attenuator, typically by using an attenuator control. Advancing or retarding the loop phase is accomplished by instructing a phase shift controller to vary the phase within the feedback loop.

By directly controlling the loop gain and the loop phase in response to changes to the error signal, which reflects changes in the transmitter operating environment, rapid adjustments can be made to the linear transmitter in order to maintain a desired stable, linear operation without training. This provides substantial flexibility between the transmission of information while maintaining stability and linearity within the transmitter. Although the preferred embodiment acts to control loop gain using variable attenuators placed between the modulation source and the summing junction, and further controls loop phase in the down conversion path, those skilled in the art will recognize alternative means. For example, loop phase may be controlled by varying the phase of the local oscillator applied to the up converter 224. Loop gain may be alternatively controlled using a variable gain stage placed in the up conversion and/or down conversion paths.

FIG. 9 is a block diagram of a two-way communication device or radio 900 which utilizes a linear transmitter according to the principles of the present invention. The radio 900 includes a receiver section 910 and a transmitter section 920 which allow it to operate in receive and transmit modes. The receiver section 910 and the transmitter section 920 support the transmitting and receiving of communication signals for the radio 900. In the receive mode, the radio 900 receives a communication signal via an antenna 901. A transmit/receive (T/R) switch 902 couples the received communication signal to a filter 903 which provides the desired selectivity for the received communication signal. The output of the filter 903 is applied to a well-known receiver IF section 904 which recovers the baseband signal. The output of the receiver IF section is applied to a well-known audio section 905 or digital sink 913 which, among other things, amplifies audio messages and presents the messages to a speaker 906. In the transmit mode, audio messages are input via a microphone 907 or digital source 911, the output of which is applied to a well-known complex baseband modulator 908 to provide a modulating signal for a linear power amplifier 912. The linear transmitter 912 utilizes the principles of the present invention to process the output of the complex baseband signal modulator 908. The output of the linear transmitter 912 is applied to the antenna 901 through the T/R switch 902 for transmission.

The present invention provides significant advantages over approaches used in the prior art. The linear transmitter does not utilize an isolator, thus avoiding the associated weight, size, and costs. Yet the linear transmitter provides smooth adjustments in response to changing conditions to maintain linearity and stability. Moreover, these adjustments can be made without delay and without imposing significant constraints on transmissions. The result is a linear transmitter capable of rapidly adjusting to changes in operating environment while providing a desirable stable, linear response.

While the preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A method for providing a linear transmitter, comprising the steps of:

providing a transmitter portion having an amplification stage, and a negative feedback correction loop with a feedback signal;

combining a reference signal for amplification and the feedback signal to produce an error signal for coupling to the amplification stage;

determining a difference between the reference signal and the error signal; and

varying transmitter parameters when the difference between the reference signal and the error signal exceeds a particular threshold, including the step of generating a training waveform and using the training waveform to adjust gain and phase parameters within the transmitter.

2. The method of claim 1, wherein the step of varying transmitter parameters, comprises the steps of:

providing an attenuator for controlling modulation level of the reference signal; and

causing the attenuator to vary the modulation level of the reference signal.

3. The method of claim 1, further comprising the step of comparing the error signal against upper and lower threshold boundaries.

4. The method of claim 1, further comprising the steps of: placing the transmitter in a preferred state;

coupling the error signal to a keyed automatic gain control system; and

using the keyed automatic gain control system to scale the error signal when the transmitter is in the preferred state.

5. The method of claim 4, wherein the step of placing the transmitter in a preferred state comprises the step generating a training waveform to set attenuation and phase adjustment parameters and the step of using the keyed automatic gain control system to scale the error signal comprises the step of determining scaling for the error signal immediately following the adjusting of gain and phase parameters using the training waveform.

6. The method of claim 1, wherein the step of combining a reference signal comprises the step of providing a reference signal having an in-phase signal component and a quadrature signal component.

7. The method of claim 6, further comprising the step of generating upper and lower threshold boundaries for the in-phase signal component and for the quadrature signal component.

8. The method of claim 10, wherein the step of generating upper and lower threshold envelopes comprises the steps of: adding a first constant to a particular signal component to generate an upper threshold value; and

subtracting a second constant from the particular signal component to generate a lower threshold value.

9. A method for operating a transmitter, comprising the steps of:

combining an input signal for amplification with a feedback signal from a negative feedback correction loop of the amplification stage to produce an error signal for coupling to an amplification stage;

generating an upper threshold boundary and a lower threshold boundary for comparisons between the error signal and the input signal; and

generating a training waveform to adjust parameters within the transmitter when the error signal is outside the upper threshold boundary or the lower threshold boundary.

10. A method for operating a transmitter, comprising the steps of:

combining an input signal for amplification with a feedback signal from a negative feedback correction loop to

produce an error signal for coupling to an amplification stage;  
generating an upper threshold boundary and a lower threshold boundary for comparisons between the error signal and the input signal; and  
adjusting transmitter parameters based on a determination of a quadrant in which the input signal lies and on whether a crossing occurs for a particular threshold boundary.

11. A method for providing a linear transmitter, comprising the steps of:

providing a reference signal having a reference in-phase signal component and a reference quadrature signal component;

combining the reference in-phase signal component and the reference quadrature signal component with corresponding feedback signals from respective feedback loops to produce an error signal having an error in-phase signal component and an error quadrature signal component;

generating first and second threshold envelopes each having an upper boundary and a lower boundary, for the error in-phase signal component and for the error quadrature signal component, respectively, based on the reference signal;

determining a quadrant for the reference signal;

determining threshold crossing characteristics when both the error in-phase signal component and the error quadrature signal component of the error signal are outside the first and second threshold envelopes, respectively; and

adjusting parameters for the transmitter based on the quadrant of the reference signal and on the threshold crossing characteristics.

12. The method of claim 11, wherein the step determining a quadrant comprises the step of determining when the reference signal is in a first quadrant, a second quadrant, a third quadrant, or a fourth quadrant.

13. The method of claim 12, wherein the step of determining threshold crossing characteristics comprises the steps of:

determining that a first threshold characteristic exists when the error in-phase signal component exceeds the upper boundary of the first threshold envelope and the error quadrature signal component exceeds the upper boundary of the second threshold envelope;

determining that a second threshold characteristic exists when the error in-phase signal component exceeds the lower boundary of the first threshold envelope and the error quadrature signal component exceeds the lower boundary of the second threshold envelope;

determining that a third threshold characteristic exists when the error in-phase signal component exceeds the upper boundary of the first threshold envelope and the error quadrature signal component exceeds the lower boundary of the second threshold envelope; and

determining that a fourth threshold characteristic exists when the error in-phase signal component exceeds the lower boundary of the first threshold envelope and the error quadrature signal component exceeds the upper boundary of the second threshold envelope.

14. The method of claim 13, wherein the step of adjusting parameters for the transmitter comprises the steps of:

reducing gain for a feedback loop when there exists one of:

the first threshold characteristic exists and the reference signal is in the third quadrant;  
the second threshold characteristic exists and the reference signal is in the first quadrant;  
the third threshold characteristic exists and the reference signal is in the second quadrant; and  
the fourth threshold characteristic exists and when the reference signal is in the fourth quadrant;

increasing gain for a feedback loop when there exists one of:

the first threshold characteristic exists and the reference signal is in the first quadrant;  
the second threshold characteristic exists and the reference signal is in the third quadrant;  
the third threshold characteristic exists and the reference signal is in the fourth quadrant; and  
the fourth threshold characteristic exists and when the reference signal is in the second quadrant.

15. The method of claim 14, wherein the step of reducing gain and the step of increasing gain comprise the step of instructing an attenuator to adjust modulation level of the reference signal.

16. The method of claim 13, wherein the step of adjusting parameters for the transmitter comprises the steps of:

retarding phase of a feedback loop when there exists one of:

the first threshold characteristic exists and the reference signal is in the fourth quadrant;  
the second threshold characteristic exists and the reference signal is in the second quadrant;  
the third threshold characteristic exists and the reference signal is in the third quadrant; and  
the fourth threshold characteristic exists and when the reference signal is in the first quadrant;

advancing phase of a feedback loop when there exists one of:

the first threshold characteristic exists and the reference signal is in the second quadrant;  
the second threshold characteristic exists and the reference signal is in the fourth quadrant;  
the third threshold characteristic exists and the reference signal is in the first quadrant; and  
the fourth threshold characteristic exists and when the reference signal is in the third quadrant.

17. The method of claim 11, wherein the step of generating first and second threshold envelopes comprises the steps of:

adding a first constant to a particular signal component to generate an upper threshold value; and  
subtracting a second constant from the particular signal component to generate a lower threshold value.

18. A linear transmitter apparatus having variable transmitter parameters, comprising:

an attenuator coupled to a modulation source and a reference signal for amplification as an output;

a negative feedback correction loop having a feedback signal;

a summing junction coupled to the reference signal and the feedback signal and summing the reference signal and the feedback signal to provide an error signal;

an amplification stage coupled to the error signal;

a keyed automatic gain control system coupled to the reference signal and to the error signal and having an output of a scaled error signal;

a comparator coupled to the reference signal and to the scaled error signal and having a particular output signal

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when a difference between the reference signal and the scaled error signal exceeds a threshold; and a controller responsive to the particular output signal to vary the transmitter parameters; wherein the keyed automatic gain control system is responsive to a training waveform triggered in response to the particular output signal to adjust the scaled error signal.

19. The linear transmitter apparatus of claim 18, wherein the controller comprises an attenuator controller coupled to the attenuator.

20. The linear transmitter apparatus of claim 18, wherein the controller comprises a phase shift adjuster coupled to the feedback signal.

21. The linear transmitter apparatus of claim 18, further comprising:

a threshold generator coupled to the reference signal and to the comparator; and a variable gain amplifier coupled between the error signal and the comparator.

22. A linear transmitter apparatus having variable transmitter parameters, comprising:

a modulation source providing an input signal for amplification comprising a first signal component and a second signal component;

first and second circuitry portions coupled to the first signal component and the second signal component, respectively, each circuitry portion comprising:

an amplification stage having a negative feedback correction loop that provides a feedback signal; a summing junction coupled to the respective signal component and to the feedback signal, and providing an error signal as input to the amplification stage; a threshold generator that generates a threshold envelope having an upper boundary and a lower boundary for the error signal;

a threshold crossing decoder coupled to the first and second circuitry portions, the threshold crossing decoder providing threshold crossing characteristics when the error signals for the first and second circuitry portions are simultaneously outside the first and second threshold envelopes, respectively;

a quadrant determiner coupled to the first and second circuitry portions, the quadrant determiner having an output based on a quadrant that characterizes the input signal;

adjustment apparatus coupled to the first and second circuitry portions and operable to initiate an adjustment to a particular based on a combination of the threshold

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crossing characteristics and the quadrant of the input signal.

23. The linear transmitter apparatus of claim 22, wherein first signal component is an in-phase signal component and the second signal component is a quadrature signal component.

24. The linear transmitter apparatus of claim 22, wherein the adjustment apparatus comprises an attenuator controller coupled to the input signal.

25. The linear transmitter apparatus of claim 22, wherein the adjustment apparatus comprises a phase shift adjuster coupled to the feedback signal.

26. A communication device, comprising:

an antenna;

a modulation source providing an input signal comprising a first signal component and a second signal component;

a transmitter coupled between the modulation source and the antenna, the transmitter comprising:

first and second circuitry portions coupled to the first signal component and the second signal component, respectively, each circuitry portion comprising:

an amplification stage having a negative feedback correction loop that provides a feedback signal; a summing junction coupled to the respective signal component and to the feedback signal, and providing an error signal as input to the amplification stage; a threshold generator that generates a threshold envelope having an upper boundary and a lower boundary for the error signal;

a threshold crossing decoder coupled to the first and second circuitry portions, the threshold crossing decoder providing threshold crossing characteristics when the error signals for the first and second circuitry portions are simultaneously outside the first and second threshold envelopes, respectively;

a quadrant determiner coupled to the first and second circuitry portions, the quadrant determiner having an output based on a quadrant that characterizes the input signal;

adjustment apparatus coupled to the first and second circuitry portions and operable to initiate an adjustment to a particular based on a combination of the threshold crossing characteristics and the quadrant of the input signal;

wherein the communication device has no isolators between the modulation source and the antenna.

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